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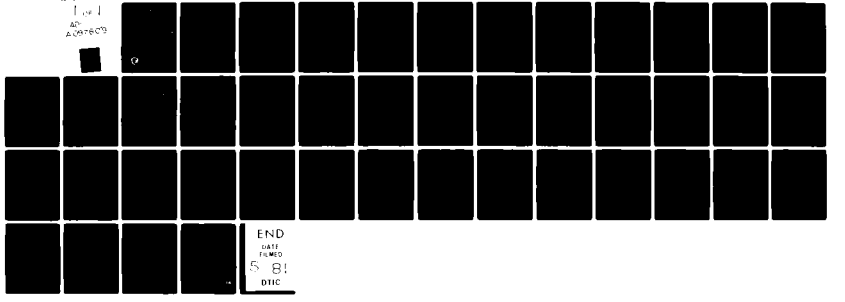

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AIR MASS CONSIDERATIONS IN FOG OPTICAL MODELING

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FEBRUARY 1981

By

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US Army Electronics Research and Development Command
ATMOSPHERIC SCIENCES LABORATORY
White Sands Missile Range, NM 88002

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Measurements of fog and haze drop-size distributions taken during the last 4 years at various locations in Germany have been analyzed to determine relations for prediction of infrared extinction coefficients from visibility (actually meteorological range).

Mie calculations were applied to the measured drop-size distributions to compute the extinction coefficient at 0.55μm, 4μm, and 10μm. For given values

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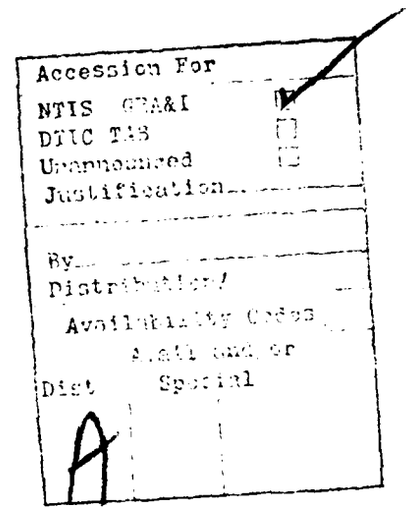
20. ABSTRACT (cont)

of the meteorological range between 1 and 4 km it was observed that the variation in the extinction coefficient at both 4 μm and 10 μm exceeded an order of magnitude. The data sets were then subdivided according to the air mass which prevailed over the measurement site at the time of the measurements. With this subdivision according to air mass type the data spread was reduced to ranges which are considered reasonable for measured data. Figures are included which depict this behavior.

Algorithms have been developed for predicting the extinction coefficient at 4 μm and 10 μm from values of the extinction coefficient at 0.55 μm. Separate algorithms have been determined for three different air mass types: maritime arctic, maritime polar, and continental polar.

ACKNOWLEDGMENTS

The authors thank Messers R. D. Loveland and A. F. Lewis, of the US Army Atmospheric Sciences Laboratory, for providing much of the data used in this analysis and Dr. R. C. Shirkey also of the US Army Atmospheric Sciences Laboratory and Mrs. Joanne Esperaza, of the Physical Science Laboratory, New Mexico State University, for assisting with the computations.



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INTRODUCTION

United States and NATO military forces are increasingly relying on new sophisticated weapons systems which employ electro-optical (EO) sensors or systems in their principles of operation. The presence of fog seriously degrades the effectiveness of visible and infrared systems, no matter how well-designed and engineered the system may be. The operational capability of a given system can, at least conceptually, be determined through well-characterized field tests. However, it is somewhat impractical as well as uneconomical to field test each device under the different fog conditions which can be expected. A more economical and logical approach is to characterize the optical properties of the various types of fogs and develop microphysical and optical models which can be used for evaluation of systems performance.

The single most important microphysical characteristic of a fog is its size distribution, N(r), since the other quantities often used to describe the fog are easily obtained from the size distribution. N(r) is usually interpreted to be the number of suspended water drops (assumed to be spherical) of radius r. From a mathematical standpoint, a more proper interpretation is N(r) = dN/dr where N is the total concentration of suspended water droplets. N(r) is expressed in units of particles per cubic centimeter per unit (micrometer) radius interval. Other microphysical quantities which are frequently used include the mean radius, the mode radius, and the liquid water content. All these quantities are easily computed from the size distribution (compare Low et al,[1] McCartney[2]).

There are several types of fogs. Most major fog types have been classified by Willett[3] and Byers.[4] According to Juisto[5] the type of fog can be influenced by several factors such as geographic location, synoptic air mass, season of the year, and time evolution of a given fog. Unfortunately, there have been no definitive studies aimed at the determination of the relative importance of these various factors in terms of their influence on the size distribution. The size distributions shown in figure 1 suggest that the formation mechanism alone is not sufficient for discriminating the major characteristics of N(r). This figure shows four of the size distribution models obtained by

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[1]R. D. H. Low, L. D. Duncan, and R. B. Gomez, 1978, The Microphysical Basis of Fog Optical Characterization, ASL-TR-0011, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[2]E. J. McCartney, 1976, Optics of the Atmosphere, John Wiley and Sons, New York, NY

[3]H. C. Willett, 1928, "Fog and Haze," Monthly Weather Review, 56:435

[4]H. R. Byers, 1959, General Meteorology, McGraw-Hill, New York, NY, 481 pp

[5]J. E. Juisto, 1979, Considerations in the Optical Characterization of the Atmosphere, ASL-TR-79-0001-3, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

Tamperi and Tomasi[6] by fitting Diermendjian's[7] modified gamma function to published drop-size data. RF1 and RF2 denote their radiation fog models 1 and 2 while AF1 and AF2 denote their advection fog models 1 and 2. There is clearly very little difference between RF1 and AF1 and between RF2 and AF2. There were probably other factors which played a significant role in determining the size distributions shown in figure 1. It would be improper, and perhaps erroneous, to conclude from these data that there is not a difference between typical size distributions for radiation and advection fogs. Proper investigation of this question would require an analysis of data taken under conditions where the formation mechanism is the only variable which changes (that is, the other factors mentioned above are the same).

In this report data collected during three different field experiments conducted during the last 2 years in Germany will be analyzed to investigate the differences in the optical and microphysical properties under different air masses.

AIR MASSES OVER CENTRAL EUROPE

According to Berry et al[8] an air mass is defined as an extensive portion of the atmosphere which is approximately homogeneous in its horizontal distribution of temperature, humidity, and lapse rate. The initial properties of an air mass are primarily influenced by its source region (the region where the air mass originates). When an air mass leaves its source region, it has properties characteristic of that portion of the earth's surface. These properties are subject to modification as the air mass passes over other areas. Berry et al discusses major source regions, air mass types, and air mass properties.

Geb[9] has classified and discussed air masses over middle Europe. His classification scheme contains eighteen separate categories (including subcategories and mixed categories). A preliminary analysis of European weather maps indicates that the more frequently occurring air masses over Europe are, in order of occurrence, the maritime polar (mP), the maritime arctic (mA), and the continental polar (cP). mP air over Europe usually originates as cP air over North America and reaches Europe through various trajectories across the Atlantic Ocean, thereby becoming modified to a maritime air mass. The source

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[6]F. Tamperi and C. Tomasi, 1976, "Size Distribution Models of Fog and Cloud Droplets in Terms of the Modified Gamma Function," Tellus, 28:333-347

[7]D. Diermendjian, 1964, "Scattering and Polarization Properties of Water Clouds and Hazes in the Visible and Infrared," Appl Opt, 3:187-196

[8]F. A. Berry, E. Bollay, and N. R. Beers, editors, 1945, Handbook of Meteorology, McGraw-Hill, New York, NY

[9]M. Geb, 1973, "Die Anveendung der Objektivierten Luftmassen-Klassification für Mittleuropa," des Institut für Meteorolgie, Berlin, GE

region for mA air is the arctic region between Greenland and Spitsbergen, while the source region for cP air over Europe is over northern Russia, Finland, and Lapland.

Air masses are generally characterized by their temperature and moisture properties. Since the different air masses originate over distinctly different regions of the earth's surface, a reasonable hypothesis is that each air mass contains aerosols and condensation nuclei which are distinctly different from those of other air masses. If this is true, then fogs formed under different air mass types can be expected to possess different microphysical properties.

MODELING OF FOG OPTICAL PROPERTIES

In the development of optical models to be used in the analysis of the performance of EO sensors and weapons systems, one is usually concerned with the extinction coefficient and the scattering phase function. Both of these quantities may be computed from Mie theory if the drop-size distribution is known. The extinction coefficient, $K(\lambda)$, for a given wavelength is related to the size distribution by

$$K(\lambda) = \pi \int r^2 N(r)\, Qext(r,\lambda)\, dr$$

Where $Qext(r,\lambda)$ is the Mie extinction parameter for wavelength λ and radius r.

If optical fog models are to be useful to nonatmospheric specialists, the models must be constrained to respond to meteorological and atmospheric inputs which are typically available in standard meteorological observations and analyses. Over the past few years visibility has become a popular variable as a predictand for extinction coefficients in the infrared regions. There are probably two reasons for this. First, visibility is a routinely observed optical property of fogs (as well as nonfoggy conditions). In addition, no other routinely observed quantity correlates well with infrared extinction coefficients. Several authors (Stewart,[10] Turner et al[11]) have shown that models which depend upon visibility alone can lead to substantial errors. The data shown in a later section indicate that much of this uncertainty can be removed if an air mass classification is also included.

THE DATA BASE

Three rather large sets of fog microphysical data were available for this study. During late February and early March of 1978, the US Army Atmospheric Sciences Laboratory (ASL) conducted a field experiment at Meppen, Germany, to

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[10] D. A. Stewart, 1977, Infrared and Submillimeter Extinction by Fog, TR-77-9, Technology Laboratory, Physical Science Directorate, Redstone Arsenal, AL

[11] R. E. Turner et al, 1978, Model Development for E-O SAEL: Natural Aerosol, Contrast, Laser Transmission and Turbulence, SAI-78-008-AA(II), Science Application Inc., Ann Arbor, MI

obtain a data base for investigating the vertical structure of fog. Ground-based measurements of fog/haze drop-size distributions were made with a Particle Measuring Systems (PMS) FSSP-100 light scattering device (commonly known as a Knollenberg counter) which measures drop sizes from 0.25μm to 23.5μm radius. At the same time, an identical instrument was operated suspended from a balloon to investigate the vertical variation of the fog. Complete observations of the size distribution were completed every 50 s. Size distribution models have been curve fit to the ground-based data by Duncan and Low.[12] Empirical formulas which reproduce the vertical variation observed with the airborne instrument have been obtained by Duncan et al.[13]

Either clear or light haze conditions persisted during many days of the Meppen experiment. Extensive periods of fog data were obtained on 18 and 22 February and 3 and 4 March, with visibilities ranging from a few kilometers to less than 100 m. An mA air mass prevailed over Meppen on 18 February. During the other 3 days Meppen was under the influence of an mP air mass.

During November 1978 the US Army Night Vision and Electro-Optics Laboratory, in cooperation with the German Ministry of Defense, conducted an extensive experiment at Grafenwöhr, Germany, to obtain data relative to the effects of the "dirty battlefield" on the performance of EO weapons systems and sensors. The ASL provided meteorological support and participated in some of the scientific experiments. Fog size distributions were measured on 9, 10, 13, 14, 15, 16, and 20 November under varying fog conditions. A different PMS light scattering instrument was used for these measurements. This instrument was the CSAS-100 which measures particles in the size range of 0.2μm to 16μm radius. Grafenwöhr was under the influence of a continental air mass during the entire period.

During late February and March 1980, the ASL conducted aerosol measurements near Greding, Germany, in support of a weapons systems test. The measurements were similar to those made at Meppen in the sense that airborne and ground-based PMS FSSP-100 were employed. Because of the high density of air traffic required by the tests, the balloon flights were restricted to one ascent each morning at about 0700 and another at about 1700 each afternoon. This schedule limited each data collection period to between 30 and 45 min.

The data collected at Greding have been reported by Lindberg et al.[14] During most of the observations, light to medium haze conditions were encountered. However, on 29 February and 20 and 24 March the balloon-borne sensor measured

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[12] L. D. Duncan and R. D. H. Low, 1980, Bi-Model Fog Models for Meppen, Germany, ASL-TR-0056, US Army Atmospheric Sciences Laboratory, White Sands Missile Range, NM

[13] L. D. Duncan, J. D. Lindberg, and R. D. Loveland, 1980, An Empirical Model of the Vertical Structure of German Fogs, US Army Atmospheric Sciences Laboratory Technical Report (in press)

[14] J. D. Lindberg et al, 1980, Vertical Distribution of Fog and Haze near Greding, Germany, during February and March 1980, US Army Atmospheric Sciences Laboratory Technical Report (in press)

size distributions within stratus clouds which were encountered about 100 to 150 m above the surface and persisted for about a 300-m thickness. An mA air mass was over the site on 29 February and 24 March; the area was under the influence of an mP air mass on 20 March.

ANALYSIS OF THE THREE DATA SETS

Mie calculations were applied to the size distributions data to obtain extinction coefficients at various wavelengths. Figure 2 shows a cross plot of extinction coefficients for 10μm and 0.55μm. For visibilities greater than about 1 km, the spread in the data is considerable. For a given value of visible extinction coefficient, the 10μm extinction coefficient can vary by an order of magnitude or more. This much variation is clearly unacceptable if one is attempting to determine the performance characteristics of an EO device operating at or near 10μm wavelength.

The data shown in figure 2 have been separated according to the three air mass categories (mA, mP, and cP) discussed above and have been replotted for each air mass in figures 3, 4, and 5, respectively. The scatter shown in each of these plots is considerably less than that in figure 2. This difference suggests that a significant part of the scatter was not measurement error but was due to the differences in air mass types. If the remaining scatter within a single air mass type (as shown in figures 3, 4, and 5) is presumed to be due primarily to experimental error, then the regression line fit to these data provides an acceptable procedure for determining the extinction coefficient at 10μm from values of the extinction coefficient at 0.55μm. The equations for these regression equations are:

$$\text{mA air mass:} \quad \log K_{10} = 1.19 \log K_{.55} - 0.45$$

$$\text{mP air mass:} \quad \log K_{10} = 1.51 \log K_{.55} - 1.01$$

$$\text{cP air mass:} \quad \log K_{10} = 1.82 \log K_{.55} - 1.65$$

Cross plots for extinction coefficient at 4μm are shown in figures 6, 7, and 8. As with the previous results, the scatter about the regression is within reason, and the regression lines provide a reasonable formation for relating the two extinction coefficients. The regression equations are:

$$\text{mA air mass:} \quad \log K_{4} = 1.03 \log K_{.55} + 0.03$$

$$\text{mP air mass:} \quad \log K_{4} = 1.32 \log K_{.55} - 0.38$$

$$\text{cP air mass:} \quad \log K_{4} = 1.58 \log K_{.55} - 0.82$$

CONCLUDING REMARKS

Air mass analysis has been employed as a tool for the analysis of extinction coefficients computed from fog drop-size distributions. It has been demonstrated that the separation of the data into groups identified by a common air mass results in data sets which allow for the development of simple relationships, through regression analysis, between extinction coefficients at two different wavelengths. The significance of these findings is considered more noteworthy because data measured at three widely separated locations during three different time periods could be combined to produce good results. In addition, a few data points reported by Abele et al[15] are included in figure 5 and show that these results compare well with measurements performed by the German Forschungsinstitut für Optik.

As was shown in figure 2, an attempt to infer infrared extinction from knowledge of visible wavelength extinction (or a meteorological visibility observation) alone will generally lead to a result that is not much better than an order of magnitude estimate. Part of this uncertainty is no doubt due to some type of measurement error. However, based on the encouraging results presented here, the conclusion is that a major part of the problem is that different air mass types tend to differ in general droplet size distributions leading to scaling law differences. Therefore, knowledge of the air mass type in addition to visible light extinction can level to better estimates of infrared extinction.

The fog drop-size distributions are currently being analyzed to determine if the air mass classification also produces sufficient similarity in drop-size distributions to allow for the development of models of drop-size distributions to be expected under the different air masses.

[15] J. Abele, H. Raidt, and D. H. Hohn, 1979, "Studies on the Influence of Meteorological Parameters on Atmospheric Laser Transmission," Forschungsinstitut für Optik, Tubingen, GE, Ffo 1979/20

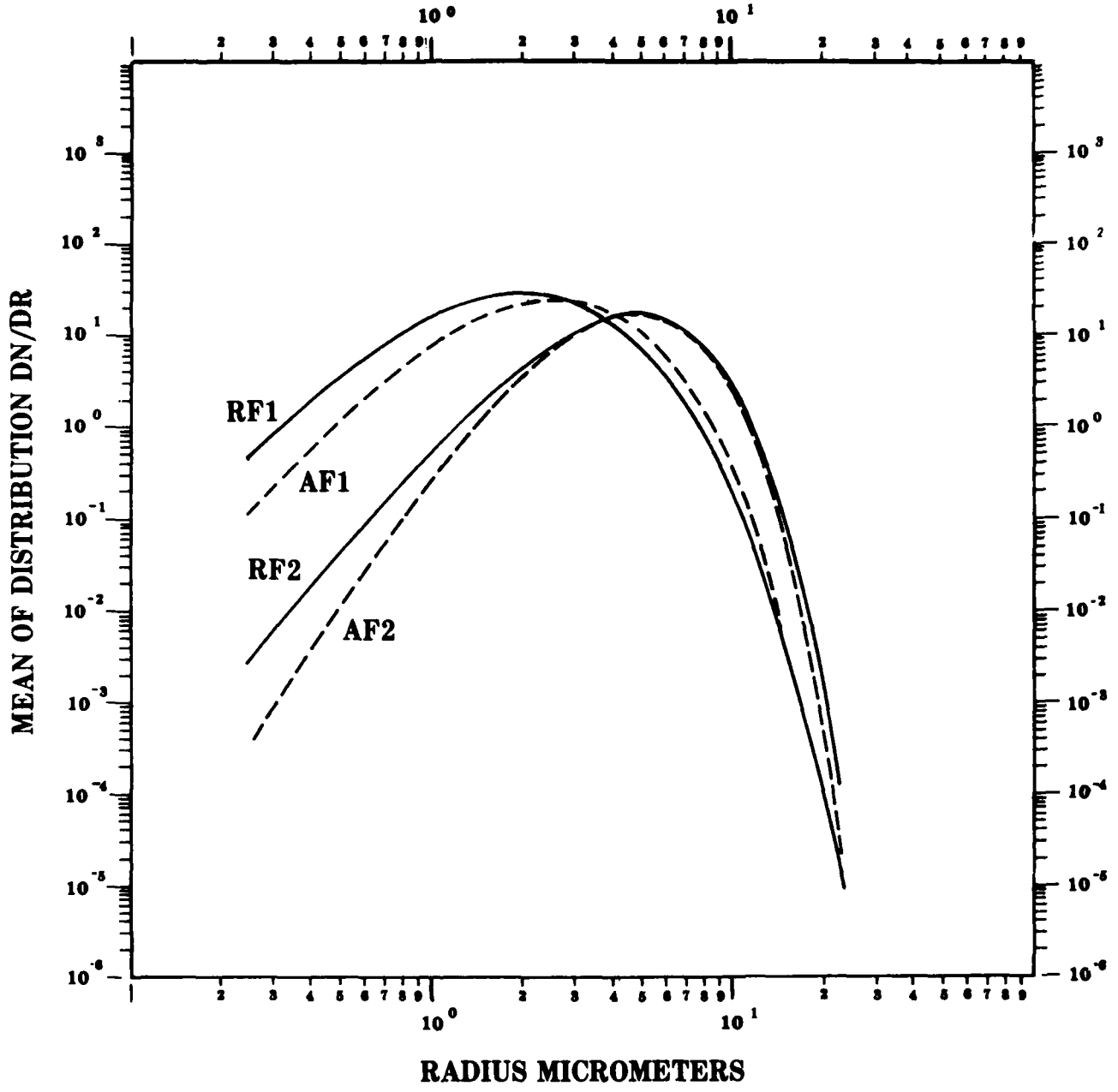

Figure 1. Size distribution for selected models for radiation and advection fogs.

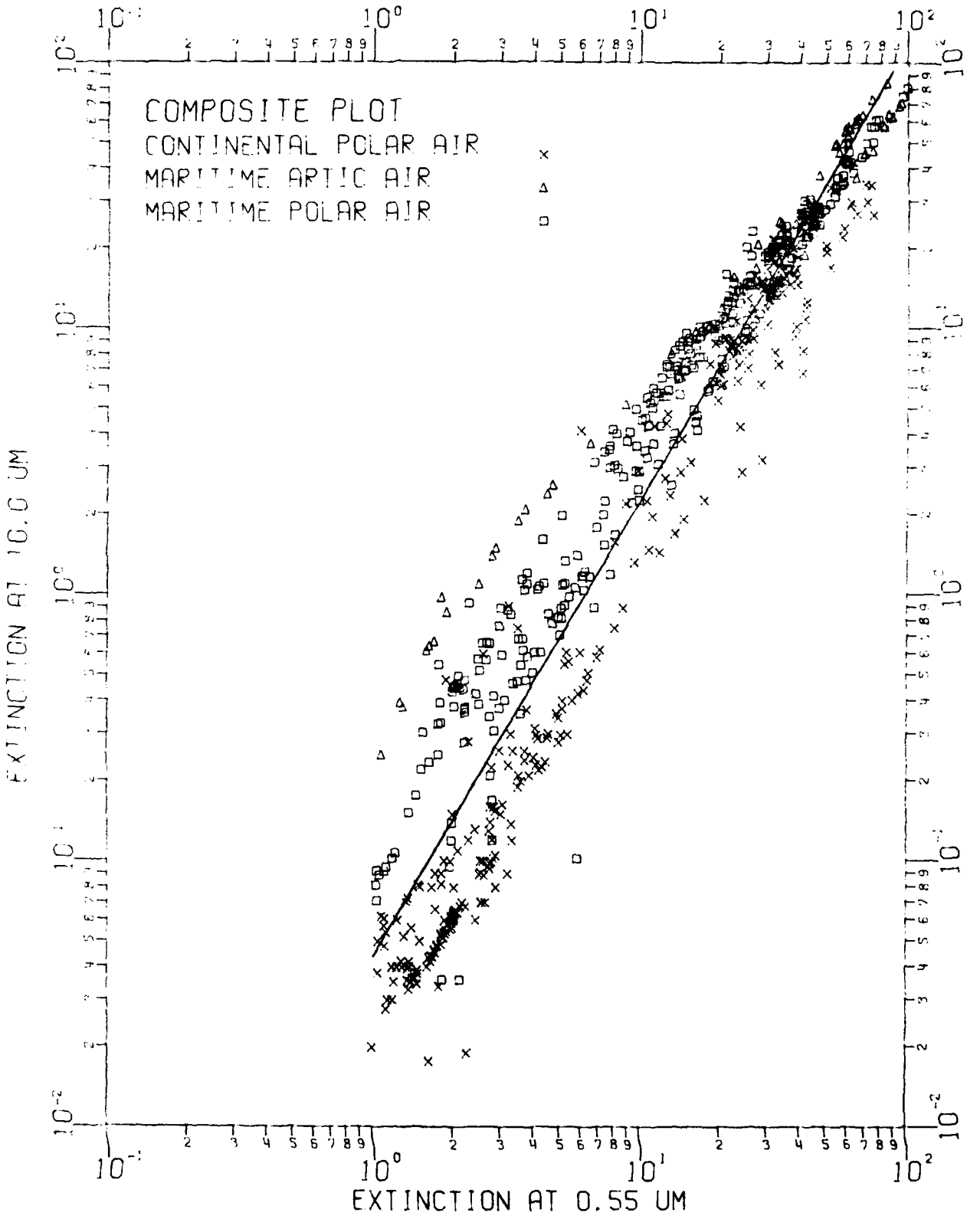

Figure 2. Composite plot of extinction coefficient at 10μm versus extinction coefficient at 0.55μm. Units are reciprocal kilometers.

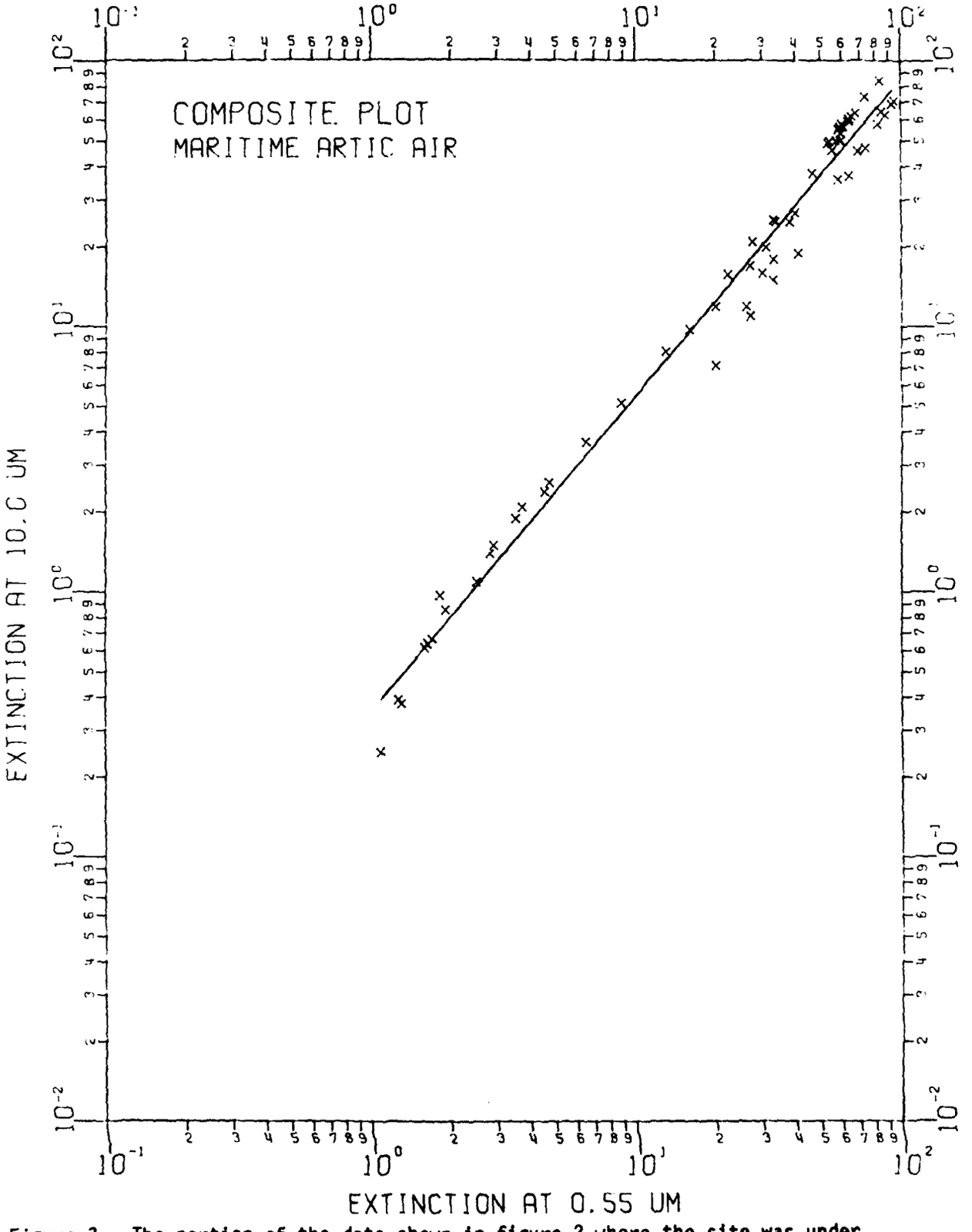

Figure 3. The portion of the data shown in figure 2 where the site was under a maritime arctic air mass. Units are reciprocal kilometers.

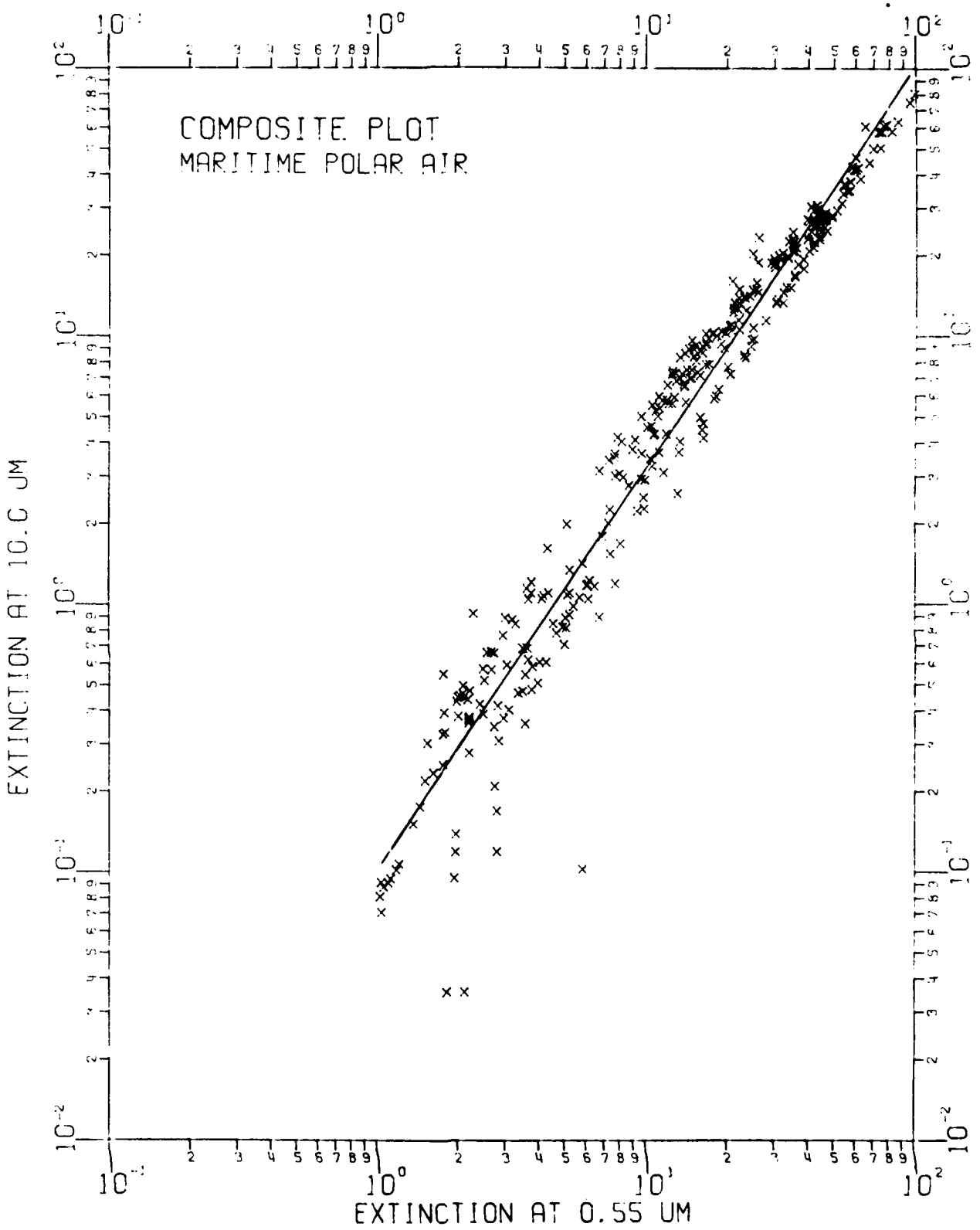

Figure 4. Same as figure 3 except for maritime polar air mass.

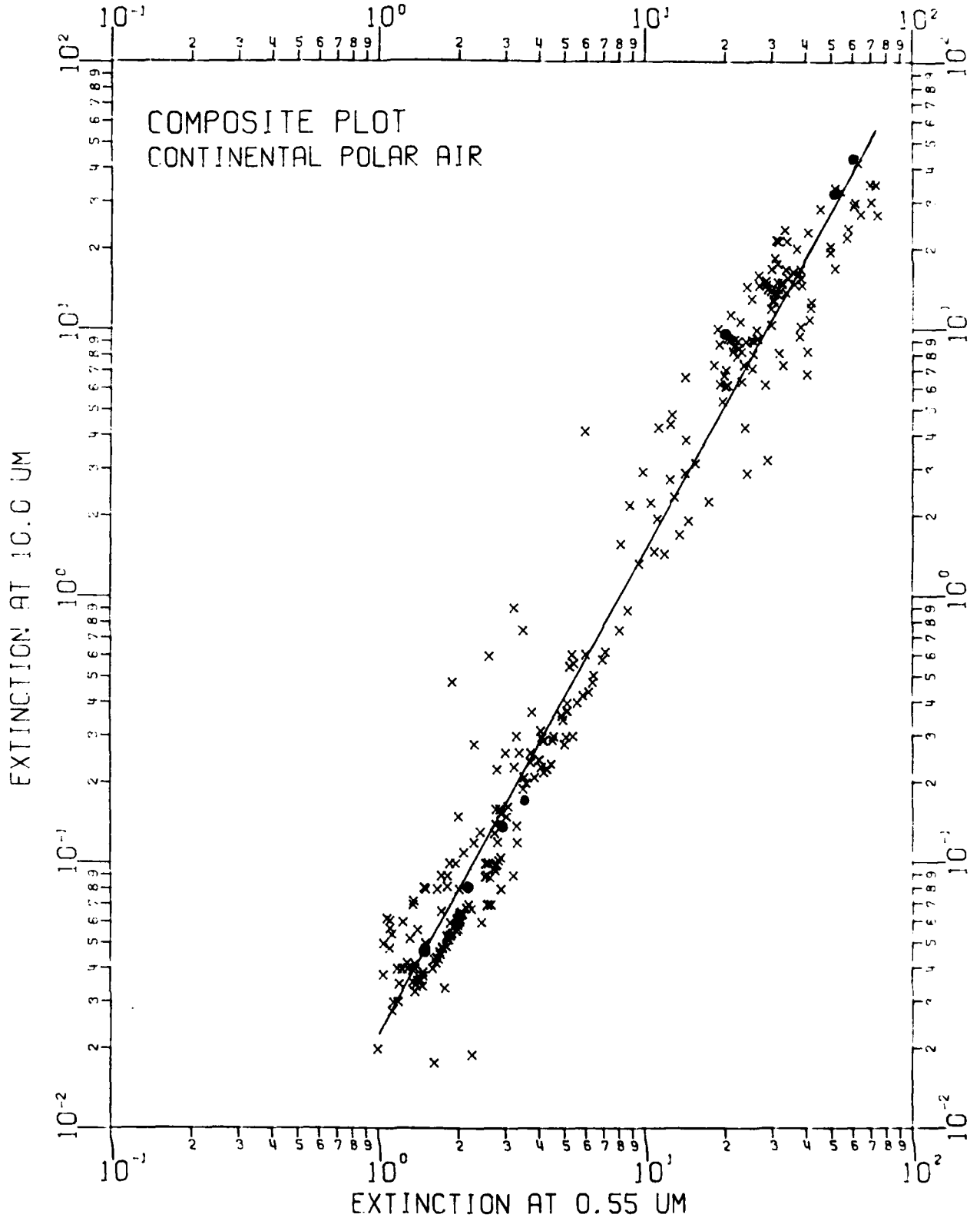

Figure 5. Same as figure 3 except for continental polar air mass.

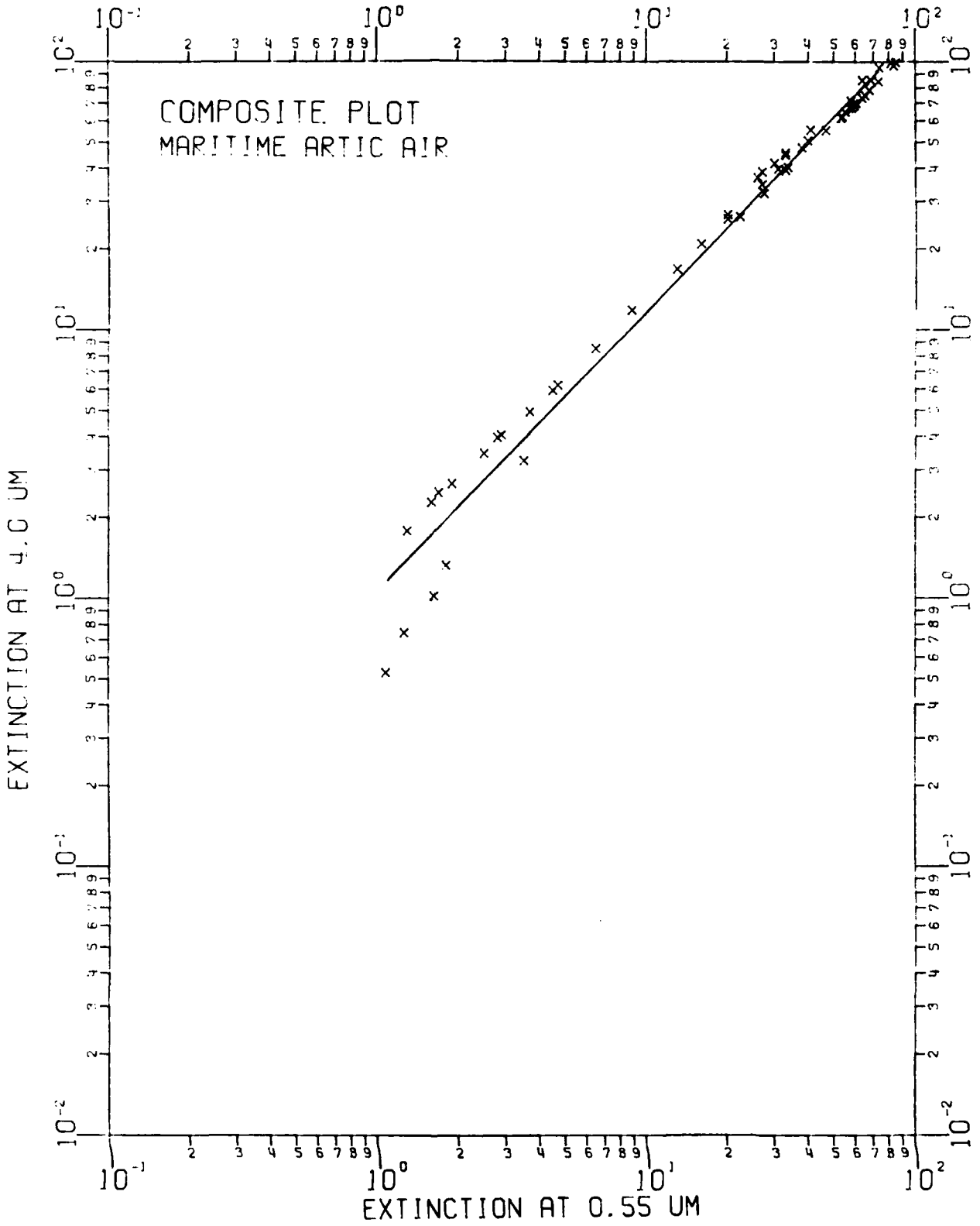

Figure 6. Same data as shown in figure 3 except infrared wavelength is 4μm.

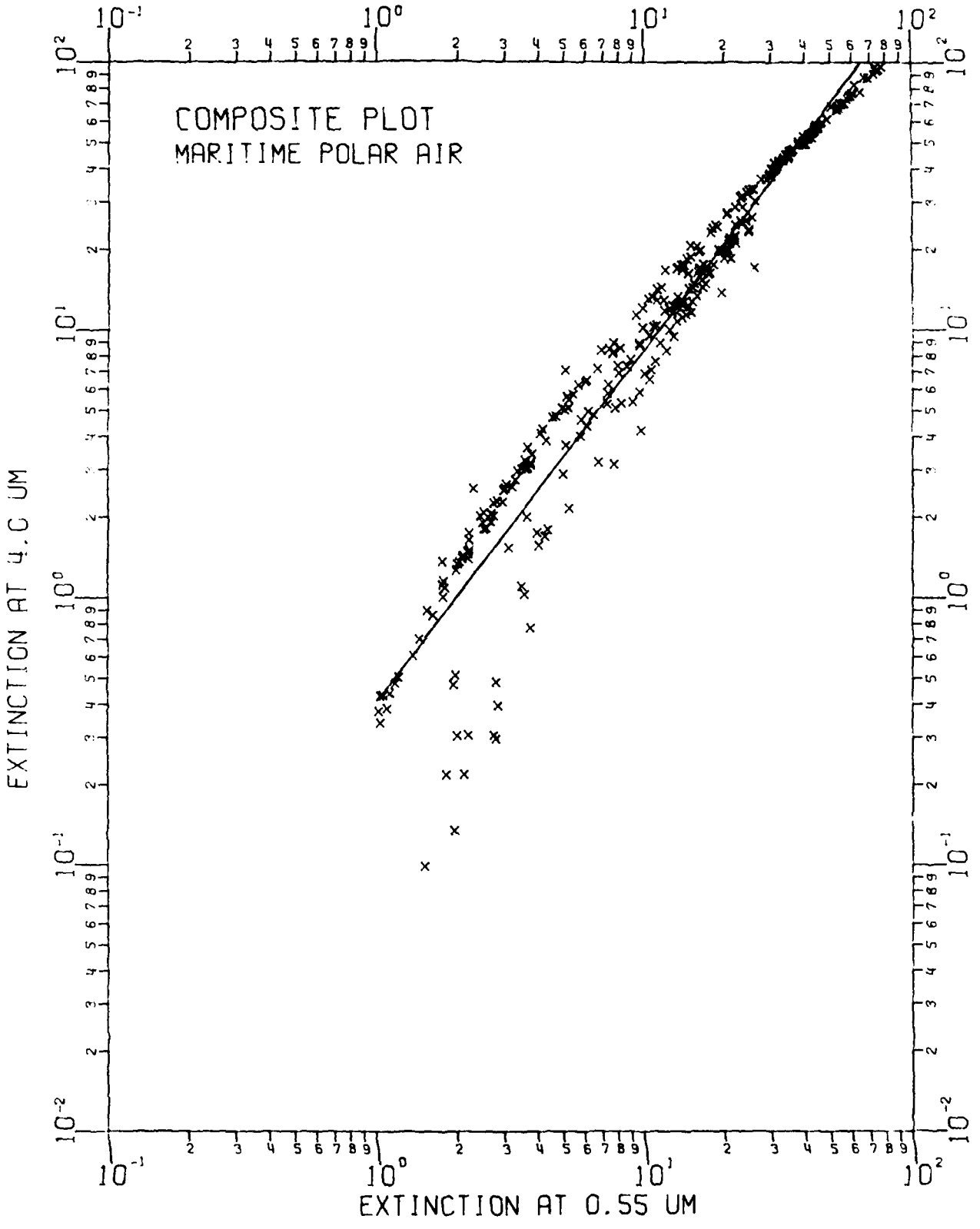

Figure 7. Same data as shown in Fig. 4 except infrared wavelength is 4μm.

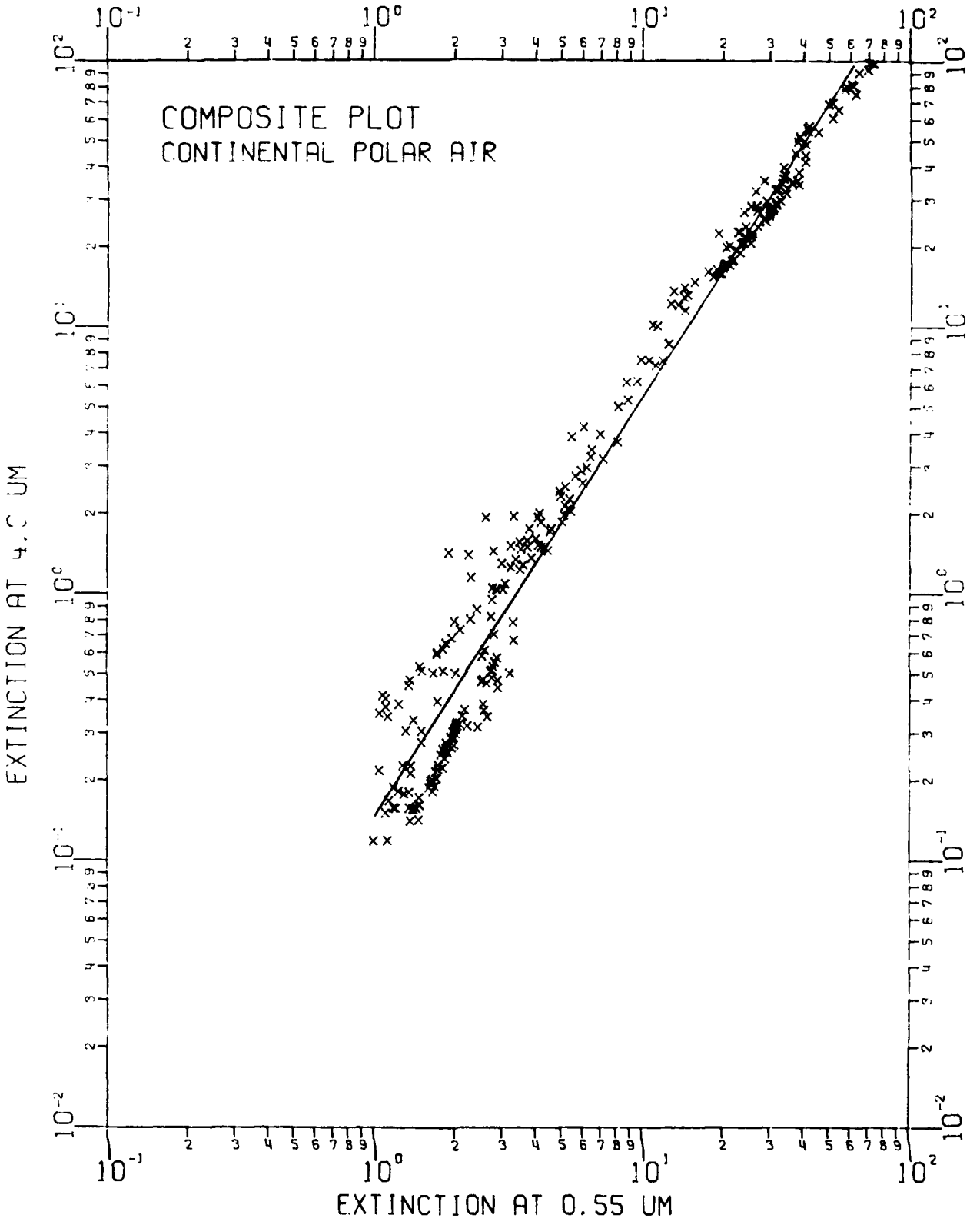

Figure 8. Same data as shown in Fig. 5 except infrared wavelength is 4μm.

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15. Abele, J., H. Raidt, and D. H. Hohn, 1979, "Studies on the Influence of Meteorological Parameters on Atmospheric Laser Transmission," Forschungsinstitut für Optik, Tubingen, GE, Ffo 1979/20.

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